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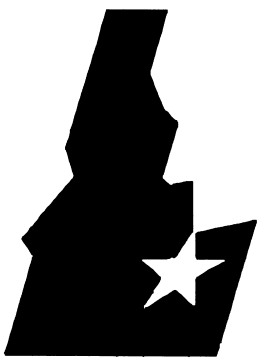
RESULTS OF ELECTRIC VEHICLE SAFETY ISSUES SURVEY



Idaho National Engineering Laboratory

U.S. Department of Energy • Idaho Operations Office

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RESULTS OF ELECTRIC VEHICLE SAFETY ISSUES SURVEY

Conducted on behalf of Ad Hoc EV Battery Readiness Working Group
In-Vehicle Safety Sub-Working Group

June 1996

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Abstract

This report documents the results of a survey conducted in the winter of 1994-1995 by the In-Vehicle Safety Sub-Working Group, a working subunit of the DOE-sponsored ad hoc EV Battery Readiness Working Group. The survey was intended to determine the opinions of a group of industry experts regarding the relative importance of a list of some 39 potential safety concerns, grouped into 8 broad areas related to electric vehicles and their battery systems. Participation in the survey was solicited from the members of the Battery Readiness Working Group, along with members of the SAE EV Battery Safety Issues Task Force and selected other knowledgeable individuals. Results of the survey questionnaire were compiled anonymously from the 38 individuals who submitted responses.

For each of the 39 issues, survey respondents ranked them as having high, medium or low importance in each of three areas: the likely severity of events involving this concern, the probability that such events will occur, and the likelihood that mitigating action for such events may be needed beyond normal industry practices. The accumulated responses from this ranking activity are tabulated, and the response totals are also provided by several subgroupings of respondents. Additionally, large numbers of written comments were provided by respondents in the 8 general areas, and these are summarized with numbers of responses indicated.

A preliminary statistical analysis of the tabulated results was performed but did not provide a satisfactory ranking of the concerns; it has not been included in this report. A list is provided of the 15 concerns which a majority of the respondents indicated could be of both medium-to-high severity and medium-to-high probability of occurrence. This list will be reviewed by the In-Vehicle Safety Sub-Working Group to determine the status of actions being taken by industry or government to mitigate these concerns, and the likelihood that additional research, standards development or regulation may be warranted to address them.

RESULTS OF ELECTRIC VEHICLE SAFETY ISSUES SURVEY

Background

In 1990 the U. S. Department of Energy sponsored a workshop aimed at identifying regulatory barriers to the commercialization of electric vehicles with advanced sodium-sulfur batteries. This workshop led to the formation of the Ad Hoc Electric Vehicle Battery Readiness Working Group, whose mission is to assure a continuing industry-government dialogue on potential obstacles to EV success in three areas: (1) battery shipping, (2) battery recycling and reclamation, and (3) battery in-vehicle safety. Each of these areas is the subject of a sub-working group which meets from one to three times a year to review activities, including potential regulations, progress on industry standards, and the results of relevant research.

As part of its function, the In-Vehicle Safety Sub-Working Group continues to examine potential safety concerns for electric vehicle battery systems. In the winter of 1994-1995, this group gathered data for an opinion survey on the significance of a large number of such concerns. This report documents the results of this survey. Its findings will be used primarily as input to the group=s contining deliberations on the adequacy of progress (by both industry and government) in addressing these concerns. The report is being made publicly available because it is considered to contain a relatively comprehensive list of EV safety concerns, and some suggestions regarding their mitigation, which may be of use to others.

Definition of Potential Safety Concerns

Prior to the conduct of the survey whose results are described here, a list of potential electric vehicle safety concerns or issues was evolved by a group of government and industry specialists using conventional Abrainstorming@ techniques. The members of this group were promised anonymity so that a free exchange of ideas could be assured. A list of some 44 concerns was developed, and this list was presented in a paper. (See Reference 1.) The list was subsequently discussed at length in a meeting of the In-Vehicle Safety Sub-Working Group, where it was (a) limited to those issues having some relation to EV batteries, and (b) couched in terms of potential hazards to users or other affected groups of persons. This revised list formed the basis for the subsequent survey.

Conduct of Safety Survey

The population selected for the survey consisted of present and past participants in the Battery Readiness Working Group itself, members of the SAE EV Battery Safety Issues Task Force, and some other individuals who were recommended as knowledgeable by members of the sub-working group. The survey was conducted anonymously, so respondents were asked to indicate only their affiliation in one of the following 7 groups. There were a total of 38 responses from the seven respondent groups (representing slightly more than 25% of the persons invited to participate), distributed according to the numbers shown in parentheses as follows:

a. Automobile manufacturers (10)
b. Battery Manufacturers (9)
c. Electric Utility Industry (2)
d. Consultant (2)
e. Dept. of Energy (3)
f. Other government agency (5)
g. Government laboratory or other contractor (7).

The survey instrument devised for this effort was a questionnaire, which is included in a reduced size format as Appendix B. The survey asked questions in the following major topical areas:

1. Battery Electric isolation (4 questions)
2. Battery Voltage/Current Interruption and Continuity (5 questions)
3. Access to Battery Voltage (4 questions)
4. Battery Mechanical Integrity (2 questions)
5. Battery Temperature (2 questions)
6. Battery Chemicals (7 questions)
7. Battery Interface (8 questions)
8. Procedures and Public information (7 questions).

For each of the 39 specific concerns tabulated in Appendix A, the respondents were asked to indicate their judgment as to the relative importance of the concern (categorized as High, Medium or Low) in three ways:

- **$** Severity, i.e., how serious might the consequences of events involving this concern be?
- **$** Probability of occurrence, i.e., how often are such events or circumstances likely to occur?
- **$** Likelihood of non-mitigation, i.e., how likely is it that the concern will not be adequately mitigated by the normal manufacturer design, test or other control measures. (This was intended to determine whether the respondents felt that additional research, regulations, or industry standards were needed in particular areas.)

Results of Safety Survey

The results of this categorization are collected in Table 1 following, where each entry shows the total number of respondents who indicated either High, Medium or Low importance for the three categories described above, for each of the 39 concerns. This tabulation includes all responses received. Appendix A includes tabulations of the responses received from each of the 7 groups separately (except that utility and consultant data were grouped together because of the small number of responses.) It also includes tabulations of the industry responses (all automotive, battery and utility respondents combined) and government responses (all DOE, other government, and government laboratory/contractor respondents combined.)

Table 1. Summary of Safety Issues Survey Responses

Concern	Severity Rating			Probability of Occurrence			Likelihood of Non-Mitigation		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
1a. Hazard due to poorly defined high voltage electric isolation requirements	21	9	3	5	12	12	1	6	22
1b. Hazard due to battery/electrical system degradation over life due to abuse, weathering, vibration etc.	20	8	5	12	15	5	3	11	17
1c. Post-crash shock hazard to occupants and emergency responders	21	6	4	8	12	11	2	10	18
1d. Shock hazard due to battery immersion	13	8	7	0	12	17	5	11	14
2a. Hazard due to inappropriate devices for short circuit interruption	22	5	7	3	15	14	2	7	22
2b. Battery failure due to malfunction of terminals/ connections/ etc.	6	15	13	2	16	14	4	7	23
2c. Battery continuity inappropriately maintained or lost due to effects of battery immersion	9	13	11	0	10	23	7	10	18
2d. Critical system malfunction due to battery control software failures	11	12	9	3	12	16	3	12	15
2e. Hazard due to incompatible functions for fail-safe systems (e.g. need for both circuit continuity and circuit interruption	9	13	8	0	9	2	2	11	16
3a. Hazard involving charger/battery safety interface (interlocks/ grounding/ application of voltage/etc.)	25	7	3	1	16	16	0	3	29

Concern	Severity Rating			Probability of Occurrence			Likelihood of Non-Mitigation		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
3b. Inadvertent contact with battery voltage due to inappropriate physical barriers or disconnects	25	7	3	1	8	24	2	2	28
3c. Hazard involving access to battery voltage due to tampering	28	5	2	3	11	18	4	11	17
3d. Electrical shock hazard during battery shipping/installation/ handling	16	7	12	1	11	21	2	5	25
4a. Failure of battery restraints/containment/ integrity during accidents/ rollovers/etc.	18	16	2	7	16	11	5	9	18
4b. Mechanical hazards in battery handling (due to weight/lack of special tools or procedures/etc.)	6	15	13	2	11	18	4	8	18
5a. Personnel burns due to battery overheating/ insulation failure/etc.	4	22	11	1	7	26	1	7	25
5b. Secondary fire due to battery overheating/ insulation failure/etc.	18	12	8	1	8	24	1	12	21
6a. Chemical exposure due to fire involving vehicle	14	16	5	1	14	20	8	9	16
6b. Chemical exposure during battery shipping, installation or handling	3	11	22	3	4	28	4	5	24
6c. Chemical exposure due to leakage/ spillage due to crash or rollover	14	15	7	5	17	12	4	15	13
6d. Hazard due to accidents involving incompatible batteries/ chemicals	8	12	15	3	3	29	4	8	21
6e. Chemical exposure due to component failure (pumps/tanks/etc.)	6	15	13	0	15	18	3	11	19

Concern	Severity Rating			Probability of Occurrence			Likelihood of Non-Mitigation		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
6f. Explosion/ignition/ fire due to battery failure, abuse or degradation (e.g. battery gassing)	15	13	8	3	14	18	4	13	16
6g. Chemical hazard due to battery immersion	5	8	21	0	9	25	4	9	19
7a. Hazard due to charger/battery safety interface (e.g. connector/ interlocks/grounding/ application of voltage)	25	7	4	3	17	13	1	4	26
7b. Hazard due to battery interchange (user or aftermarket)	8	12	14	2	14	18	1	11	20
7c. Battery failure due to control or thermal management failures or overcharge/ overdischarge	12	16	8	12	18	4	0	14	18
7d. Battery or system control equipment failure due to electromagnetic susceptibility	6	7	21	0	11	22	1	6	24
7e. Battery failures due to ambient temperature extremes	4	13	19	2	15	16	3	3	27
7f. Explosion/ignition/ fire due to failure of battery ventilation systems	15	12	8	1	13	20	0	9	23
7g. Hazard due to mechanical hazards in battery handling	4	18	14	2	13	18	2	11	20
7h. Critical system malfunction due to battery control software failures	12	16	6	4	10	19	3	12	17
8a. Hazard due to inadequate battery-related procedures/ training for service persons	25	9	2	11	13	10	4	11	18

Concern	Severity Rating			Probability of Occurrence			Likelihood of Non-Mitigation		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
8b. Hazard due to inadequate battery-related procedures/ training for emergency personnel	21	11	3	9	16	7	4	14	15
8c. Chemical exposure due to inadequate maintenance practices or procedures	7	20	8	2	16	16	3	9	21
8d. Mechanical hazards in battery handling due to inadequate procedures	4	14	18	3	11	20	2	8	23
8e. Battery hazards due to inadequate knowledge by users or public	17	13	7	9	15	10	3	17	13
8g. Hazards due to inadequate battery-related safety and warning displays or labels	14	5	17	3	8	23	3	2	28
8f. Failure to identify other battery-related hazards due to inadequate tracking/reporting of safety incidents	12	10	14	4	13	17	3	11	19

Note: The orderinig of the last two items in the table (8g and 8f) was unintentionally reversed in the original survey, and the order has been retained in all data tables in this report for consistency.

Analysis of Survey Results

The original intent of categorizing responses with respect to severity, probability of occurrence, and likelihood of non-mitigation was to permit a conventional risk assessment approach to be applied to interpreting the data. In some generic sense, the product of these three factors represents a measure of risk associated with each concern. However, the wide variety of responses, coupled with a varying number of responses to each question, led to the conclusion that a quantitative ranking of all the issues based on this measure would be confusing. Both the summary and detailed data are provided in this report so that this or other analytical approaches can be applied if desired.

The data was also subjected to a preliminary statistical analysis to determine whether there were statistically significant indications of priorities from the respondents among the various issues treated. The approach to this analysis was somewhat simplistic, and the results were not conclusive. Further, discussion of these results in the sub-working group made it clear that such

an analysis would be likely to engender a great deal of controversy because of the multiplicity of ways it could be approached or interpreted. As a consequence, the results of this statistical analysis are not included in this report.

As an approach to imposing at least some structure on the results, a process of elimination was was considered instead. Those issues which a majority of the respondents believed would have low severity were removed from the list. Of the remaining issues, those which a majority of the respondents believed would have a low probability of occurrence were also removed. The remaining issues (15 of the original 39) were then ranked in decreasing order of their average Alikelihood of non-mitigation@, i.e. those which were judged (based on average score) most likely to require additional research, standards or regulation were placed higher in the list. The resulting list, included as Appendix C, is intended primarily as a basis for discussion at future meetings of the In-Vehicle Safety Sub-Working Group. No conclusions are drawn in this report as to the significance of these results.

Comments From the Survey

In addition to the specific topics categorized in each of the eight survey areas, a generic question was asked for each area, and respondents were invited to provide written comments. This was intended to allow them to identify topics or issues that may not have been included in the >specific concerns= list, as well as to suggest approaches for dealing with the concerns. A majority of the respondents did in fact provide some written comments. Because of the large volume of these comments and their free form nature, they have been summarized for each of the primary survey questions as follows. The numbers in parentheses represent the number of comments from the respondents that are considered to be included or subsumed by the generalized item shown. The total number of responses exceeds the number of respondents for some questions because multiple conditions were listed. In general the responses for each subject have been ranked in decreasing frequency of occurrence.

1. Under what conditions must the battery maintain a minimum of <u>TBD</u> megohm electrical isolation between the high-voltage dc battery circuit and the vehicle chassis?

- Under all conditions (including crashes, submersion, anticipated failure conditions) (14)
- Under all except the most extreme conditions (e.g. crashes beyond FMVSS levels, submersion in water) (7)
- Under normal operating, maintenance etc. conditions (but not necessarily crashes) (3)
- Miscellaneous specific technical or battery specific comments (3)

2. Under what conditions must the battery high-voltage dc circuit continuity be interrupted?

- Crash (14)
- Service, maintenance or repair (12)
- Ground fault or loss of isolation (8)
- When vehicle is not operating (including during charging) (6)
- System failures or faults external to battery (6)
- Short circuit (6)
- Currents beyond normal operating values (3)
- Tampering or inadvertant access (2)
- General accident conditions (1)
- Shipping (1)

Under which of these conditions (if any) must the battery circuit continuity be restorable automatically or manually?

- Service or repair conditions, after inspection or service etc. (14)
- None automatically or by operator (not otherwise specified) (5)
- Manually by operator after trip (4)
- Implied manual reset (e.g. to move vehicle from hazardous area or if ground fault) (4)
- Automatically after trip (under some conditions, e.g. no faults) (4)

Under what conditions must the battery maintain continuity of the high-voltage dc circuit?

- Vehicle operation / normal driving (14)
- As necessary to be able to move vehicle for safety reasons (incl. bumps, isolation loss etc.) (9)
- Charging (3)
- None (2)
- For service purposes (1)

3. Under what conditions must the battery design preclude access to the high-voltage dc circuit by unauthorized personnel?

- All conditions (12)
- Operation, routine maintenance, show or casual user (7)
- All conditions except for maintenance/repair access (6)
- Not precluded but difficult under all conditions (3)
- All conditions except as required for charging (2)
- Post-accident (2)
- During battery shipment and installation (1)
- Access should be permitted but difficult and hazards clearly marked (1)

4. Under what conditions must the mechanical integrity of the battery assembly be maintained?

- All conditions except the most severe accidents (e.g. crashes above FMVSS levels) (19)
- Under all conditions (8)
- All ›reasonable‹ shipping conditions (2)
- 5 mph crashes (1)
- Normal installation handling (1)
- Rough road driving (1)
- Miscellaneous not otherwise categorized (3)

5. Under what conditions must the battery external surfaces not exceed <u>TBD</u> C?

- Various suggested values for max temperature included 40, 50, 70, 80, 82, 100, 140 C
- All conditions (5)
- All conditions except the most severe accidents/crashes (5)
- All normal operating or non-crash conditions (4)
- Surfaces exposed to (ordinary) human contact should be limited (4)
- Should be shielded or limited to temperatures that will not cause combustion (3)
- General (condition not specified) limit suggested (3)
- Shipping, maintenance, repair, charging, other special mode (3)
- Not required/possible/practical (2)
- Continuous operation at high environmental temperature (1)

6. Under what conditions must the battery completely contain all hazardous substances?

- All conditions except the most severe accidents (e.g. crashes beyond FMVSS limits etc.) (16)
- Always/all accident scenarios (3)
- Normal operating conditions and/or minor accidents (controlled leakage okay otherwise) (3)
- Leakage okay if personnel not exposed (e.g. none in passenger compartment) (2)
- Shipping, installation, servicing etc. activities (2)

- All except required battery venting (2)
- Miscellaneous not otherwise categorized (2)

7. What battery/vehicle interface conditions must be imposed to assure compliance of the battery with all of the above requirements?

- Battery packaging, containment and access suggestions (18)
- Interlocks, disconnect or trip devices (9)
- Battery system monitoring suggestions (6)
- Battery location, restraint, physical protection suggestions (6)
- Misc. specific design features, design verification (6)
- Single failure and fail safe suggestions (5)
- Design "philosophy" suggestions (including electrical isolation design) (4)
- Labels (2)
- Standards (2)
- Training, QA, other non-hardware (2)

8. What procedures or other information will be required to assure safe operation and use of EV batteries?

- Owner/operator manuals/training/hazards information (12)
- Service personnel manuals/training/qualification/licensing & certification (11)
- General or public training/procedures/safety documentation suggestions (10)
- Labeling for hazards & safety information (7)
- Emergency personnel training/education/manuals/hazards information (5)
- Battery assembly/shipping/handling training/manuals/procedures (3)
- Component standards (2)
- Non-procedural (mostly design) suggestions (10)

Survey Results and Conclusions

This report is intended primarily to document the response data and comments resulting from the conduct of an opinion survey of potential safety issues for electric vehicles. The survey population was drawn from a group of industry and government persons who are generally involved in some aspect of electric vehicle research, development, standards making, or regulation. In general no claim is made that this group is necessarily impartial, but it is knowledgeable regarding both the technology and its areas of potential hazard. Consequently the collection of safety concerns in this report should be reasonably comprehensive and could be of value to other groups or individuals interested in electric vehicle safety. The In-Vehicle Safety Sub-Working Group of the ad hoc EV Battery Readiness Working Group is expected to continue to review these issues, their relative importance to the successful and safe commercialization of EVs, and the progress being made by both government and industry groups in addressing them.

References

Hammel, Carol J. and Hunt, Gary L., "Identification of Safety Issues for Electric Vehicles," presented at the Twelfth International Electric Vehicle Symposium, Anaheim, CA, December 1994.

Appendix A

Compilation of Survey Response Raw Data

By Groups of Respondents

Compilation of Survey Response Raw Data By Groups of Respondents
(All entries are in the same relative order as those in Table 1 in the body of the report.)

All Industry Respondents

1a	11	5	2	4	6	6	0	3	12
1b	11	3	3	7	6	3	2	3	11
1c	9	4	4	4	5	8	0	3	13
1d	6	4	6	0	8	8	2	6	9
2a	14	3	2	2	8	8	0	3	15
2b	2	10	7	0	9	8	1	1	15
2c	3	8	6	0	5	12	1	4	12
2d	5	8	5	1	6	10	1	8	8
2e	3	10	4	0	5	12	2	6	9
3a	14	4	2	1	8	9	0	0	18
3b	15	4	1	1	4	13	1	0	17
3c	17	2	1	0	6	12	2	5	11
3d	10	4	6	0	5	13	2	2	14
4a	10	9	1	2	11	5	0	4	14
4b	3	10	6	0	8	9	3	2	11
5a	1	10	9	0	4	14	1	2	15
5b	9	5	6	0	1	16	1	3	14
6a	4	11	4	0	4	14	3	3	12
6b	0	4	15	0	2	16	2	3	13
6c	5	9	6	2	8	8	0	8	10
6d	1	8	9	0	1	17	1	3	14
6e	2	9	8	0	8	10	2	5	11
6f	7	5	6	0	8	10	1	8	9
6g	1	2	15	0	3	15	2	4	12
7a	14	4	2	2	9	6	0	3	14
7b	4	7	8	1	6	11	1	5	11
7c	7	8	5	2	8	8	0	7	11
7d	2	5	12	0	7	11	1	2	15
7e	2	4	14	1	10	7	1	1	16
7f	8	7	5	1	5	12	0	2	16
7g	0	12	8	0	8	10	1	6	12
7h	5	10	4	2	4	13	0	6	12
8a	15	3	1	4	8	5	2	6	9
8b	8	9	2	3	8	6	1	6	10
8c	2	10	6	0	7	10	1	6	10
8d	1	7	11	0	6	11	1	4	12
8e	7	8	5	2	7	8	1	7	9
8g	5	4	10	0	4	13	0	1	16
8f	7	5	7	0	7	10	2	4	10

Automotive Respondents

1a	4	4	1	0	2	5	0	2	4
1b	4	2	2	3	3	1	2	1	4
1c	4	1	3	2	2	4	0	3	4
1d	2	2	3	0	3	4	2	3	3
2a	8	2	0	0	4	3	0	2	6
2b	1	6	3	0	4	4	0	1	7
2c	1	4	3	0	1	7	1	2	5
2d	2	5	2	0	2	6	0	5	3
2e	0	6	2	0	2	6	2	3	3
3a	8	1	1	0	4	4	0	0	8
3b	8	2	0	0	2	6	1	0	7
3c	9	0	1	0	3	5	1	3	4
3d	6	3	1	0	2	6	2	2	4
4a	5	4	1	0	6	2	0	1	7
4b	1	5	4	0	5	3	2	1	4
5a	1	4	5	0	2	6	0	1	7
5b	6	1	3	0	1	6	1	2	5
6a	1	5	3	0	2	6	1	2	5
6b	0	2	7	0	2	6	1	3	4
6c	3	3	4	1	5	2	0	3	5
6d	0	3	5	0	1	7	0	3	5
6e	2	3	4	0	5	3	1	2	5
6f	3	2	4	0	3	5	1	4	3
6g	0	1	7	0	1	7	1	2	5
7a	8	1	0	0	3	3	0	1	5
7b	3	3	2	0	3	4	1	3	3
7c	3	3	3	1	1	5	0	3	4
7d	1	1	6	0	2	5	0	0	7
7e	1	1	7	1	4	2	0	1	6
7f	2	2	4	0	2	5	0	0	7
7g	0	4	5	0	4	3	0	3	5
7h	3	4	1	1	2	4	0	2	5
8a	7	1	1	1	4	2	2	3	2
8b	4	4	1	1	3	3	0	5	2
8c	1	5	2	0	5	2	0	4	3
8d	0	4	5	0	2	5	0	2	5
8e	3	3	4	2	3	2	1	4	2
8g	3	1	5	0	3	4	0	1	6
8f	3	2	4	0	3	4	1	3	2

All Government Respondents

1a	8	4	1	1	6	4	1	3	8
1b	8	4	2	5	7	2	1	6	6
1c	10	2	0	4	6	2	2	6	4
1d	5	4	1	0	3	8	2	5	4
2a	7	1	4	1	6	5	2	4	5
2b	4	3	6	2	5	6	3	2	7
2c	4	5	5	0	4	10	2	6	5
2d	4	4	4	1	5	6	1	4	6
2e	5	3	4	0	3	9	0	4	7
3a	9	3	1	0	6	7	0	2	10
3b	9	2	2	0	4	9	1	1	10
3c	9	3	1	2	4	6	1	6	5
3d	4	3	6	1	4	8	0	1	11
4a	7	6	1	4	4	6	4	4	4
4b	2	4	6	1	2	9	0	5	7
5a	2	11	2	1	3	10	0	4	9
5b	7	7	2	1	6	7	0	7	6
6a	9	5	1	1	8	6	4	5	4
6b	3	6	6	3	1	11	2	1	10
6c	7	6	1	3	7	4	4	5	3
6d	6	4	6	3	1	11	3	3	7
6e	3	5	5	0	6	7	1	4	7
6f	6	7	2	3	5	7	3	4	6
6g	3	5	6	0	5	9	1	5	6
7a	9	3	2	1	6	7	1	1	10
7b	3	5	6	1	7	6	0	5	7
7c	4	8	2	0	13	1	0	6	6
7d	4	1	8	0	4	9	0	4	7
7e	2	7	5	1	4	9	2	2	9
7f	5	5	3	0	7	7	0	7	5
7g	3	5	6	1	4	8	1	4	7
7h	6	5	2	1	6	5	2	6	4
8a	8	6	1	6	5	4	2	4	8
8b	11	2	1	6	6	1	3	6	5
8c	4	9	2	2	7	6	2	3	9
8d	2	6	7	2	4	9	1	3	10
8e	8	5	2	6	7	2	1	9	4
8g	7	1	7	3	4	8	3	1	10
8f	4	4	7	4	5	6	1	6	8

Battery Industry Respondents

1a	7	0	1	4	3	1	0	1	7
1b	6	1	1	3	3	2	0	2	6
1c	5	2	1	2	2	4	0	0	8
1d	4	2	2	0	5	3	0	3	5
2a	5	1	2	2	3	5	0	1	8
2b	1	3	4	0	4	4	1	0	7
2c	2	3	3	0	3	5	0	2	6
2d	2	3	3	0	4	4	1	3	4
2e	3	3	2	0	2	6	0	3	5
3a	6	2	1	1	3	5	0	0	9
3b	7	1	1	1	1	7	0	0	9
3c	7	2	0	0	2	7	1	2	6
3d	4	1	4	0	3	6	0	0	9
4a	5	4	0	2	4	3	0	3	6
4b	2	4	2	0	2	6	0	1	7
5a	0	5	4	0	2	7	1	1	7
5b	3	3	3	0	0	9	0	1	8
6a	3	5	1	0	2	7	2	1	6
6b	0	2	7	0	0	9	1	0	8
6c	2	5	2	1	2	6	0	4	5
6d	1	4	4	0	0	9	1	0	8
6e	0	5	4	0	3	6	1	3	5
6f	4	2	2	0	4	5	0	3	6
6g	1	1	7	0	2	7	1	2	6
7a	5	2	2	1	5	3	0	1	8
7b	1	2	6	1	1	7	0	0	8
7c	4	3	2	1	5	3	0	3	6
7d	1	3	5	0	4	5	0	1	8
7e	1	3	5	0	6	3	1	0	8
7f	5	4	1	1	2	6	0	2	7
7g	0	6	3	0	3	6	1	2	6
7h	1	5	3	1	1	8	0	3	6
8a	8	1	0	2	4	3	0	3	6
8b	4	4	1	1	5	3	1	1	7
8c	1	4	4	0	1	8	1	2	6
8d	1	2	6	0	3	6	1	2	6
8e	4	4	1	0	3	6	0	2	7
8g	2	3	4	0	1	8	0	0	9
8f	4	2	3	0	3	6	1	1	7

Utility & Consultant Respondents

1a	2	1	0	0	1	2	0	0	3
1b	2	1	0	1	2	0	0	1	2
1c	2	1	0	0	2	1	0	1	2
1d	2	0	1	0	1	2	1	0	2
2a	2	1	1	0	2	1	0	0	3
2b	0	3	0	0	3	0	0	1	2
2c	2	1	0	0	2	1	1	0	2
2d	3	0	0	2	1	0	1	0	2
2e	1	1	0	0	2	0	0	1	1
3a	2	1	0	0	3	0	0	1	2
3b	1	2	0	0	1	2	0	1	2
3c	3	0	0	1	2	0	1	0	2
3d	2	0	1	0	2	1	0	2	1
4a	1	2	0	1	2	0	1	1	1
4b	1	2	0	1	2	0	2	1	0
5a	1	2	0	0	0	3	0	1	2
5b	2	1	0	0	1	2	0	1	2
6a	1	2	0	0	2	1	1	1	1
6b	0	1	2	0	1	2	0	1	2
6c	2	1	0	0	3	0	0	3	0
6d	1	1	0	0	1	2	0	2	1
6e	1	2	0	0	1	2	0	1	2
6f	2	2	0	0	2	1	0	2	1
6g	1	1	1	0	1	2	1	0	2
7a	3	1	0	1	3	0	0	1	3
7b	1	2	0	0	3	1	0	3	1
7c	1	2	1	0	4	0	0	2	2
7d	0	2	2	0	1	3	1	1	2
7e	0	2	2	0	1	2	0	0	4
7f	3	1	0	0	2	2	0	0	4
7g	1	3	0	1	2	1	0	2	2
7h	2	2	0	1	1	2	1	1	2
8a	2	1	0	2	0	1	0	1	2
8b	2	1	0	1	2	0	0	2	1
8c	1	2	0	0	3	0	0	0	3
8d	1	2	0	1	2	0	0	1	2
8e	2	1	0	1	2	0	1	2	0
8g	2	0	1	0	0	3	0	0	3
8f	1	2	0	0	2	1	0	1	2

Other Government Respondents

1a	3	1	0	1	3	0	1	2	1
1b	3	0	1	3	1	0	1	3	0
1c	3	1	0	2	2	0	2	1	1
1d	0	2	1	0	1	3	0	1	2
2a	2	0	2	1	2	1	1	2	1
2b	2	1	2	2	3	0	2	1	2
2c	0	4	1	0	2	3	0	3	2
2d	1	3	1	0	2	3	1	1	3
2e	1	1	2	0	1	3	0	2	2
3a	3	1	0	0	4	0	0	2	2
3b	4	0	0	0	2	2	1	1	2
3c	2	1	1	1	1	2	0	3	1
3d	0	0	4	0	0	4	0	0	4
4a	3	2	0	3	0	2	2	2	0
4b	1	1	1	1	0	2	0	2	2
5a	1	4	0	1	2	2	0	3	2
5b	3	3	0	1	2	2	0	4	1
6a	4	1	0	1	3	1	1	3	1
6b	2	2	1	2	0	3	1	1	3
6c	3	1	0	2	2	0	2	2	0
6d	3	2	0	3	0	2	2	3	0
6e	0	4	1	0	1	4	0	4	1
6f	2	2	1	2	1	2	1	3	1
6g	0	1	4	0	1	4	0	2	3
7a	4	0	0	1	3	0	1	0	3
7b	2	1	1	1	3	0	0	1	3
7c	1	3	0	0	4	0	0	2	2
7d	1	1	2	0	2	2	0	2	2
7e	1	0	3	0	1	3	1	0	3
7f	1	1	1	0	2	2	0	2	2
7g	2	0	2	0	2	2	0	0	3
7h	2	2	0	0	2	2	0	3	1
8a	2	3	0	3	1	1	0	2	3
8b	5	0	0	3	1	1	2	1	2
8c	1	4	0	1	2	2	0	2	3
8d	1	2	2	1	2	2	0	1	4
8e	3	2	0	3	2	0	0	5	0
8g	3	1	1	3	1	1	3	1	1
8f	1	2	2	1	3	1	0	3	2

Department of Energy Respondents

1a	2	1	0	0	1	1	0	1	2
1b	1	3	0	2	2	0	0	1	2
1c	2	0	0	1	0	1	0	1	1
1d	2	0	0	0	0	2	1	1	1
2a	2	0	1	0	1	2	1	1	0
2b	1	0	2	0	1	2	1	1	0
2c	2	0	1	0	0	3	2	0	0
2d	2	0	1	1	1	1	0	2	0
2e	2	0	1	0	2	1	0	2	0
3a	0	1	1	0	0	2	0	0	1
3b	0	0	2	0	0	2	0	0	1
3c	1	1	0	0	0	1	0	1	0
3d	0	1	1	0	0	2	0	0	1
4a	1	0	1	0	1	1	1	0	0
4b	0	0	2	0	0	2	0	0	1
5a	0	1	2	0	0	3	0	0	2
5b	1	0	2	0	1	2	0	0	2
6a	2	0	1	0	1	2	2	0	0
6b	0	1	2	0	0	3	1	0	1
6c	2	0	1	1	0	2	2	0	0
6d	1	0	2	0	0	3	1	0	1
6e	1	0	1	0	1	1	1	0	1
6f	0	2	1	0	1	2	1	1	0
6g	1	1	1	0	0	3	1	1	0
7a	1	1	1	0	0	3	0	1	1
7b	0	2	1	0	2	1	0	2	0
7c	1	1	1	0	2	1	0	2	0
7d	2	0	1	0	1	2	0	2	0
7e	1	1	1	0	1	2	0	1	1
7f	2	0	1	0	1	2	0	2	0
7g	0	2	1	0	1	2	0	2	0
7h	2	0	1	0	2	1	1	1	0
8a	2	0	1	1	1	1	0	2	0
8b	2	0	0	1	1	0	0	2	0
8c	1	1	1	0	2	1	1	1	0
8d	1	1	1	0	2	1	0	2	0
8e	2	0	1	1	1	1	0	2	0
8g	2	0	1	0	2	1	0	0	2
8f	3	0	0	3	0	0	1	1	1

Govt. Laboratory & Contractor Respondents

1a	3	2	1	0	2	3	0	0	5
1b	4	1	1	0	4	2	0	2	4
1c	5	1	0	1	4	1	0	4	2
1d	3	2	0	0	2	3	1	3	1
2a	3	1	1	0	3	2	0	1	4
2b	1	2	2	0	1	4	0	0	5
2c	2	1	3	0	2	4	0	3	3
2d	1	1	2	0	2	2	0	1	3
2e	2	2	1	0	0	5	0	0	5
3a	6	1	0	0	2	5	0	0	7
3b	5	2	0	0	2	5	0	0	7
3c	6	1	0	1	3	3	1	2	4
3d	4	2	1	1	4	2	0	1	6
4a	3	4	0	1	3	3	1	2	4
4b	1	3	3	0	2	5	0	3	4
5a	1	6	0	0	1	5	0	1	5
5b	3	4	0	0	3	3	0	3	3
6a	3	4	0	0	4	3	1	2	3
6b	1	3	3	1	1	5	0	0	6
6c	2	5	0	0	5	2	0	3	3
6d	2	2	4	0	1	6	0	0	6
6e	2	1	3	0	4	2	0	0	5
6f	4	3	0	1	3	3	1	0	5
6g	2	3	1	0	4	2	0	2	3
7a	4	2	1	0	3	4	0	0	6
7b	1	2	4	0	2	5	0	2	4
7c	2	4	1	0	7	0	0	2	4
7d	1	0	5	0	1	5	0	0	5
7e	0	6	1	1	2	4	1	1	5
7f	2	4	1	0	4	3	0	3	3
7g	1	3	3	1	1	4	1	2	4
7h	2	3	1	1	2	2	1	2	3
8a	4	3	0	2	3	2	2	0	5
8b	4	2	1	2	4	0	1	3	3
8c	2	4	1	1	3	3	1	0	6
8d	0	3	4	1	0	6	1	0	6
8e	3	3	1	2	4	1	1	2	4
8g	2	0	5	0	1	6	0	0	7
8f	0	2	5	0	2	5	0	2	5

Appendix B

Safety Issues Survey Form

(Reduced in Size from Original)

SAFETY SURVEY FOR ELECTRIC VEHICLE TRACTION BATTERIES

Background

A list of potential safety concerns for EV batteries formulated by the In-Vehicle Safety Sub-Working Group has been categorized under 8 topics. Seven of these topics are expressed in terms of the conditions under which a battery must comply with specific criteria. This grouping is not intended to limit the list of concerns, but rather to focus the responses into those areas which will define (a) **what types of safety requirements may be needed** for or imposed on EV batteries, and (b) **what types of tests are likely to be required** to verify battery safety.

Instructions for Survey

A. For each of the eight major items, first read the generic question for this topic.

B. For each specific concern listed for each item, provide your judgment as to the **relative** importance of the concern (**H**igh, **M**edium or **L**ow) in 3 ways:

1. the **severity** of the concern (i.e. how serious might the consequences of events involving this concern or hazard be?)
2. the **probability of occurrence** of events leading to the concern or hazard (i.e. how often will such events or circumstances happen?)
3. the **likelihood that these concerns may NOT be mitigated** or eliminated by design, test or other manufacturer control measures (i.e. will the concern **NOT** be adequately addressed in the absence of additional research, or industry-wide standards or regulations?)

This means, for example, that if you judge a concern to have High severity, High probability of occurrence, and High likelihood of "non-mitigation" without additional action, it would have the highest possible level of importance for this survey.

C. Provide your answers or commentary (in narrative form) regarding the generic question(s) posed by the topic. You may use the space provided on the forms or attach a separate sheet using the item numbers.

If you as an individual respondent either have no opinion or do not feel qualified to comment on the importance of a particular area, please indicate "No Opinion" as your response to this area. Eventual assessment and scoring of the survey will take incomplete responses into account.

Respondent Information

This survey is intended to be anonymous; you do need not give your name or other information that would identify you. You are asked to indicate only your "sector" of involvement/employment with electric vehicles by checking one of the following boxes:

1. Automobile manufacturing industry	
2. Battery manufacturing or development industry	
3. Electric utility industry or other industrial segment	
4. Consultant, consulting firm etc.	
5. U. S. Department of Energy	
6. Other government agency (Federal or State)	
7. Government laboratory or other government contractor	

1. Battery Electrical Isolation

1. Under what conditions must the battery maintain a minimum of TBD megohm electrical isolation between the high-voltage dc battery circuit and the vehicle chassis?

SPECIFIC CONCERNS	Severity (H/M/L)	Probability of Occurrence (H/M/L)	Likelihood of Non-Mitigation (H/M/L)
a. Hazard due to poorly defined high voltage electric isolation requirements			
b. Hazard due to battery/electrical system degradation over life due to abuse, weathering, vibration etc.			
c. Post-crash shock hazard to occupants and emergency responders			
d. Shock hazard due to battery immersion			

2. Battery Voltage/Current Interruption and Continuity

2. Under what conditions must the battery high-voltage dc circuit continuity be interrupted?

Under which of these conditions (if any) must the battery circuit continuity be restorable automatically, or manually by the vehicle operator, or manually by service personnel in a repair facility?

Under what conditions must the battery maintain continuity of the high-voltage dc circuit?

SPECIFIC CONCERNS	Severity (H/M/L)	Probability of Occurrence (H/M/L)	Likelihood of Non-Mitigation (H/M/L)
a. Hazard due to inappropriate devices for short circuit interruption			
b. Battery failure due to malfunction of terminals/ connections/etc.			
c. Battery continuity inappropriately maintained or lost due to effects of battery immersion			

d. Critical system malfunction due to battery control software failures			
e. Hazard due to incompatible functions for fail-safe systems (e.g. need for both circuit continuity and circuit interruption)			

3. Access to Battery Voltage

3. Under what conditions must the battery design preclude access to the high-voltage dc circuit by unauthorized personnel?

SPECIFIC CONCERNS	Severity (H/ M/L)	Probability of Occurrence (H/M/L)	Likelihood of Non-Mitigation (H/M/L)
a. Hazard involving charger/battery safety interface (interlocks/grounding/ application of voltage/etc.)			
b. Inadvertant contact with battery voltage due to inappropriate physical barriers or disconnects			
c. Hazard involving access to battery voltage due to tampering			
d. Electrical shock hazard during battery shipping/installation/ handling			

4. Battery Mechanical Integrity

4. Under what conditions must the mechanical integrity of the battery assembly be maintained?

SPECIFIC CONCERNS	Severity (H/M/L)	Probability of Occurrence (H/M/L)	Likelihood of Non-Mitigation (H/M/L)
a. Failure of battery restraints/containment/ integrity during accidents/rollovers/etc.			
b. Mechanical hazards in battery handling (due to weight/lack of special tools or procedures/etc.)			

5. Battery Temperature

5. Under what conditions must the battery external surfaces not exceed TBD °C?

SPECIFIC CONCERNS	Severity (H/M/L)	Probability of Occurrence (H/M/L)	Likelihood of Non-Mitigation (H/M/L)
a. Personnel burns due to battery overheating/ insulation failure/etc.			
b. Secondary fire due to battery overheating/ insulation failure/etc.			

6. Battery Chemicals

6. Under what conditions must the battery completely contain all hazardous substances?

SPECIFIC CONCERNS	Severity (H/M/L)	Probability of Occurrence (H/M/L)	Likelihood of Non-Mitigation (H/M/L)
a. Chemical exposure due to fire involving vehicle			
b. Chemical exposure during battery shipping, installation or handling			
c. Chemical exposure due to leakage/ spillage due to crash or rollover			
d. Hazard due to accidents involving incompatible batteries/chemicals			
e. Chemical exposure due to component failure (pumps/tanks/etc.)			
f. Explosion/ignition/ fire due to battery failure, abuse or degradation (e.g. battery gassing)			
g. Chemical hazard due to battery immersion			

7. Battery Interfaces

7. What battery/vehicle interface conditions must be imposed to assure compliance of the battery with all of the above requirements?			
SPECIFIC CONCERNS	Severity (H/M/L)	Probability of Occurrence (H/M/L)	Likeli-hood of Non-Mitigation (H/M/L)
a. Hazard due to charger/battery safety interface (e.g. connector/interlocks/ grounding/application of voltage)			
b. Hazard due to battery interchange (user or aftermarket)			
c. Battery failure due to control or thermal management failures or overcharge/over-discharge			
d. Battery or system control equipment failure due to electromagnetic susceptibility			
e. Battery failures due to ambient temperature extremes			
f. Explosion/ignition/ fire due to failure of battery ventilation systems			
g. Hazard due to mechanical hazards in battery handling			
h. Critical system malfunction due to battery control software failures			

8. Procedures and Public Information

8. What procedures or other information will be required to assure safe operation and use of EV batteries?			
SPECIFIC CONCERNS	Severity (H/M/L)	Probability of Occurrence (H/M/L)	Likelihood of Non-Mitigation (H/M/L)
a. Hazard due to inadequate battery-related procedures/ training for service persons			
b. Hazard due to inadequate battery-related procedures/ training for emergency personnel			
c. Chemical exposure due to inadequate maintenance practices or procedures			
d. Mechanical hazards in battery handling due to inadequate procedures			
e. Battery hazards due to inadequate knowledge by users or public			
g. Hazards due to inadequate battery-related safety and warning displays or labels			
f. Failure to identify other battery-related hazards due to inadequate tracking/ reporting of safety incidents			

Appendix C

A Ranking of Selected Concerns Based on Survey Results

Appendix C
A Ranking of Selected Concerns Based on Survey Results

The following list consists of those 15 itemized concerns from the total of 39 concerns treated in the survey which satisfy both of the following conditions:

a. At least half of the respondents for that concern agreed that it is of either High or Medium severity.
b. At least half of the respondents for that concern agreed that it is of either High or Medium probability of occurrence.

The items in the list have been ranked in decreasing order of the respondents opinion as to the their Alikelihood of non-mitigation@, which could suggest that items nearer the top of the list are likelier candidates for additional research, standards development, or regulation than those further down. However, it should be noted that this ranking has not been shown to be statistically significant in view of the size of the survey. In any event, adjacent items in the list generally have very similar scores; and only the first and second items in the list were viewed by a majority of respondents as having High or Medium likelihood of non-mitigation.

1. (6 c) Chemical exposure due to leakage/ spillage due to crash or rollover
2. (8 e) Battery hazards due to inadequate knowledge by users or public
3. (8 b) Hazard due to inadequate battery-related procedures/training for emergency personnel
4. (4 a) Failure of battery restraints/ containment/integrity during accidents/ rollovers/etc.
5. (8 a) Hazard due to inadequate battery-related procedures/training for service persons
6. (1 b) Hazard due to battery/electrical system degradation over life due to abuse, weathering, vibration etc.
7. (8 f) Failure to identify other battery-related hazards due to inadequate tracking/reporting of safety incidents
8. (1 c) Post-crash shock hazard to occupants and emergency responders
9. (8 c) Chemical exposure due to inadequate maintenance practices or procedures
10. (7 c) Battery failure due to control or thermal management failures or overcharge/overdischarge
11. (2 b) Battery failure due to malfunction of terminals/ connections/etc.
12. (2 a) Hazard due to inappropriate devices for short circuit interruption
13. (1 a) Hazard due to poorly defined high voltage electric isolation requirements
14. (7 a) Hazard due to charger/battery safety interface (e.g. connector/interlocks/ grounding/ application of voltage)
15. (3 a) Hazard involving charger/battery safety interface (interlocks/ grounding/ application of voltage/etc.)